5 BASE ISOLATION AND DAMPING DEVICES

5.1 Overview

Buildings respond to earthquake ground shaking in different ways. When the forces on a building or the displacement of the building exceeds certain limits, damage is incurred in different forms and to different extents. If a brittle building is designed to respond elastically with no ductility, it may fail when the ground motion induces a force that is more severe than the building strength. On the other hand, if the building is designed with ductility, it will be damaged but will still be able to weather severe ground shaking without failure.

As mentioned above, some alternatives to avoid significant damage in buildings in strong ground shaking are:

1. To provide the building with unreasonably high strength (which may not be economically justified).
2. To design the building to have a normal (economically justifiable) strength following damage resistant principles; in this case despite the seismic force being larger than the building strength damage will be minimal and restricted only to easily replaceable sacrificial components.
3. To alter the building's characteristics through external intervention such that even in strong ground shaking the demand is less than the design strength of the building and its components.

Following option 1, many structural engineers use the conventional approach to protect buildings from the destructive forces of earthquakes by increasing the strength of the buildings so that they do not collapse during such events. This approach is not entirely effective in terms of protection afforded to the contents and occupants because the maximum level of ground shaking is never known with certainty. Some level of ductility should always be provided for the case of extreme ground shaking, in which case there remains the risk of permanent damage to the building.

For option 2, research on damage resistant design has gained significant momentum in the last decade and design guidelines have been developed to design structures that incur little damage despite undergoing large deformation during strong ground shaking. The low damage solutions available for concrete, steel and timber buildings are explained in the later chapters of this report.

This section explains option 3(i.e., modifying the building externally to reduce its response/demand). Broadly speaking, this can be divided into two categories:

(1) Base isolating the building from the ground shaking; and/or

(2) Modifying the building's characteristics through the use of damping devices to reduce its response, and hence reduce the damage.

Note that there can be significant overlap between these categories, because damping devices can be combined with base isolation, and can also be part of damage-resistant designs, as described later.

5.2 Base Isolation

Since the motion of earthquakes is vibrational in nature, the principle of vibration isolation can be utilised to protect a building (i.e., it is decoupled from the horizontal components of the earthquake ground motion by mounting rubber bearings between the building and its foundation). Such a system not only provides protection to the building but also to its contents and occupants.

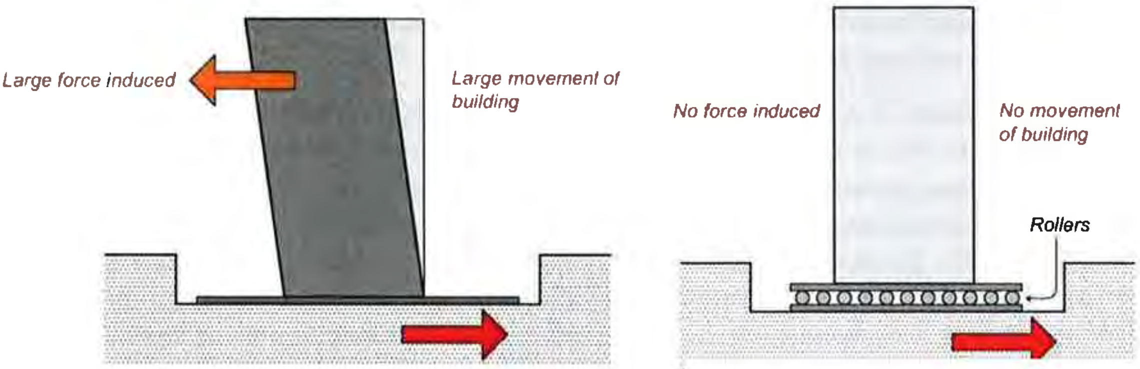
Base isolation is a passive structural control technique where a collection of structural elements is used to substantially decouple a building from its foundations resting on shaking ground, thus protecting the building's structural integrity. New Zealand is a leader in base isolation techniques, following pioneering work by Bill Robinson and Ivan Skinner (Skinner et al. 2000). Robinson Seismic Limited in Wellington is one of the leading base isolation suppliers and designers in the world. Base isolation enables a building or non-building structure (such as a bridge) to survive a potentially devastating seismic impact, following a proper initial design or subsequent modifications to the building. Contrary to popular belief base isolation does not make a building earthquake proof; it just enhances the earthquake resistance.

Base isolation can be used both for new structural design and seismic retrofit. Some prominent buildings in California (e.g., Pasadena City Hall, San Francisco City Hall, LA City Hall) have been seismically retrofitted using *Base Isolation Systems*. In New Zealand, Te Papa in Wellington and Christchurch Women Hospital are examples of base isolated new buildings, and Parliament buildings in Wellington have been seismically retrofitted. Christchurch Women's Hospital is the only base isolated building in the South Island and expectedly did not suffer any damage in the recent Canterbury earthquakes.

The concept of base isolation is explained through an example building resting on frictionless rollers; as shown in Figure 5.1(b). When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to the horizontal shaking of the ground; simply, the building does not experience the earthquake. Now, if the same building is located on flexible pads that offer resistance against lateral movements (Figure 5.1(c)), then some effect of the ground shaking will be transferred to the building above. If the flexible pads are properly chosen, the forces induced by ground shaking can be much less than that experienced by a fixed base building built directly on the ground (Figure 5.1(a)). The flexible pads shown in Figure 5.1(c) are called base-isolators, whereas the structures protected by means of these devices are called base-isolated buildings.

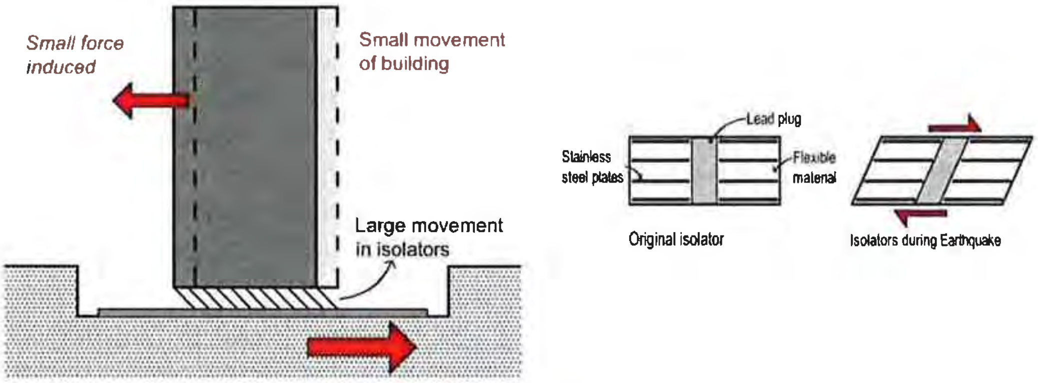
The main feature of the base isolation technology is that it introduces flexibility into the connection between the structure and the foundation. In addition to allowing movement, the isolators are often designed to absorb energy and thus add damping to the system. This helps in further reducing the seismic response of the building. Many of the base isolators look like large rubber pads, although there are other types that are based on sliding of one part of the building relative to other. It should be noted that base isolation is not suitable for all buildings. Tall high-rise buildings or buildings on very soft soil are not suitable for base isolation. Base isolation is most effective for low to medium rise buildings which are located on hard soil.

There are two basic types of base isolation systems; elastomeric bearings and sliding systems.



(a) Building resting directly on ground

(b) Building on rollers without any friction

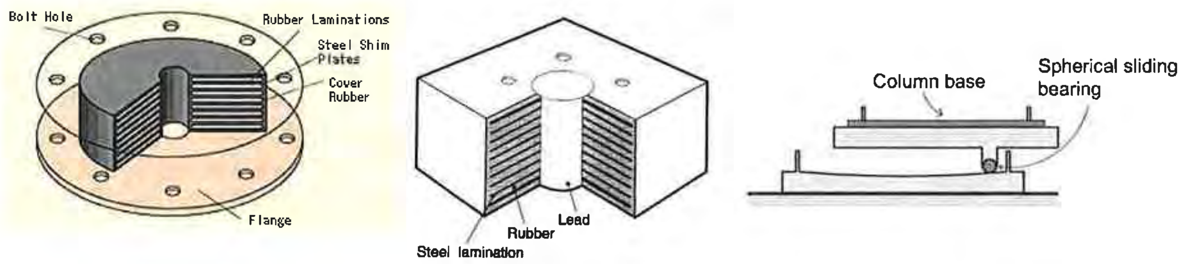


(c) Building base isolated with lead- rubber bearing.

Figure 5.1.Principles of base isolation.

5.2.1 Elastomeric bearings

The base isolation system that has been adopted most widely in recent years is typified by the use of elastomeric bearings, where the elastomer is made of either natural rubber or neoprene. In this approach, the building or structure is decoupled from the horizontal components of the earthquake ground motion by interposing a layer with low horizontal stiffness between the structure and the foundation.



(a) Laminated rubber bearing (b) Lead rubber bearing (c) Spherical rubber bearing

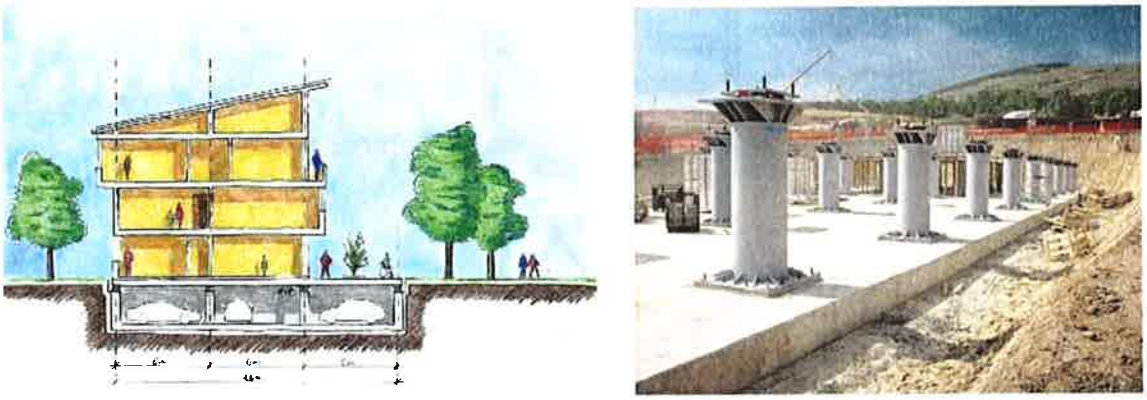
Figure 5.2. Base isolation devices.

Rubber bearings are most commonly used for this purpose; a typical laminated rubber bearing (produced by Robinson Seismic Limited in Wellington) is shown in Figure 5.2(a). A rubber bearing typically consists of alternating laminations of thin rubber layers and steel plates (shims), bonded together to provide vertical rigidity and horizontal flexibility. These bearings are widely used for the support of bridges. On top and bottom, the bearing is fitted with steel plates which are used to attach the bearing to the building and foundation. The bearing is very stiff and strong in the vertical direction, but flexible in the horizontal direction. Vertical rigidity assures the isolator will support the weight of the structure, while horizontal flexibility converts destructive horizontal shaking into gentle movement. A slightly modified form with a solid lead "plug" in the middle to absorb energy and add damping is called a lead-rubber bearing which is very common in seismic isolation of buildings, as shown in figure 5.2(b).

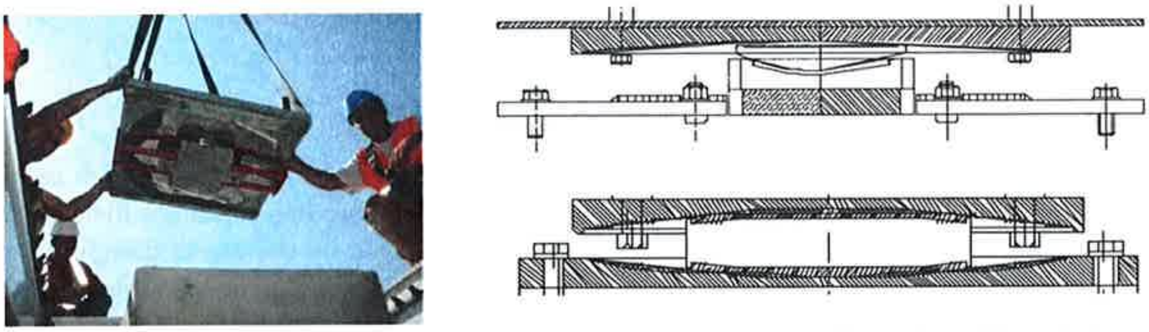
The second basic type of base isolation system is typified by the sliding system. This works by limiting the transfer of shear across the isolation interface. Many sliding systems have been proposed and some have been used. One commonly used sliding system called "spherical sliding bearing" is shown in Figure 5.2(c). In this system, the building is supported by bearing pads that have a curved surface and low friction. During an earthquake the building is free to slide on the bearings. Since the bearings have a curved surface, the building slides both horizontally and vertically. The forces needed to move the building slightly upwards place a limit on the horizontal or lateral forces.

5.2.2 Friction pendulum bearing

A similar system is the Friction Pendulum Bearing (FPB), another name of Friction Pendulum System (FPS). It is based on three aspects: an articulated friction slider, a spherical concave sliding surface, and an enclosing cylinder for lateral displacement restraint (Zayas, 1990).



(a) Schematic cross section. **(b) Base isolators on steel columns**



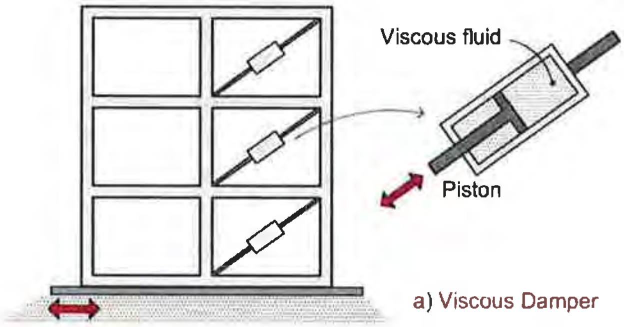
(c) Positioning a device **(d) Sections of single and double surface sliding devices**

Figure 5.3. Three-storey residential construction on base-isolated ground-floor slab (Calvi, 2010)

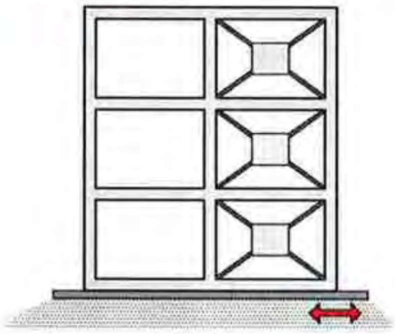
Figure 5.3 shows an example of three-storey residential construction on base-isolated ground-floor slab, as part of the reconstruction after the 2009 L'Aquila earthquake in Italy (Calvi, 2010), using "friction pendulum" devices.

5.3 Supplemental Damping Devices

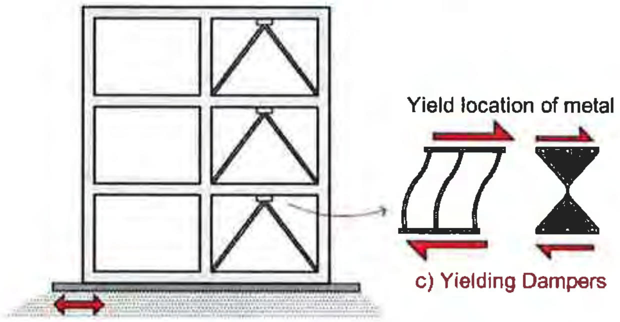
There are a number of supplemental damping devices which can absorb energy and add damping to buildings, in order to reduce seismic response. These devices can be can be combined with base isolation, or placed elsewhere up the height of the building, often in diagonal braces, or they can be used as part of damage-resistant designs, as described later.



a) Viscous Damper



b) Friction Damper



c) Yielding Dampers

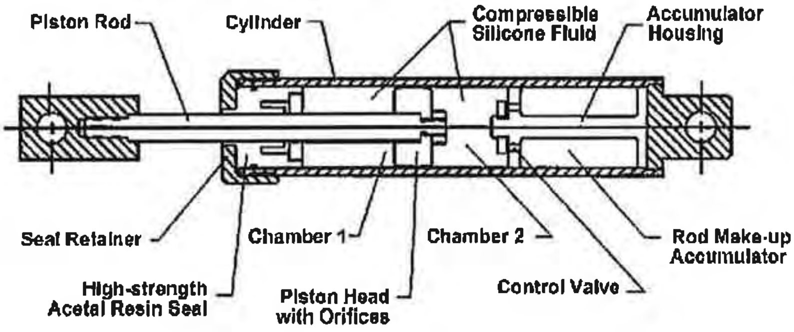
Figure 5.4. Dissipation devices.

Supplemental damping devices are especially suitable for tall buildings which cannot be effectively base-isolated. Being very flexible compared to low-rise buildings, their horizontal displacement needs to be controlled. This can be achieved by the use of damping devices, which absorb a good part of the energy making the displacement tolerable. Retrofitting existing buildings is often easier with dampers than with base isolators, especially if the application is external or does not interfere with the occupants. By equipping a building with additional devices which have high damping capacity, the seismic energy entering the building can be greatly reduced. In this concept, the dampers suppress the response of the building relative to its base.

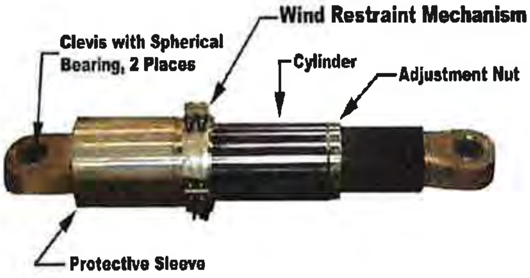
There are many different types of dampers used to mitigate seismic effects, as described below. Figure 5.4 shows typical applications of some of these dampers. More applications are shown in Chapter 7.

5.3.1 Fluid dampers

The construction of a fluid damper is shown in Figure 5.5. It consists of a stainless steel piston with bronze orifice head. It is filled with silicone oil. The piston head utilises specially shaped passages which alter the flow of the damper fluid and thus alter the resistance characteristics of the damper. Fluid dampers may be designed to behave as a pure energy dissipater or a spring or as a combination of the two. Shock-absorbers in cars are a type of fluid damper.



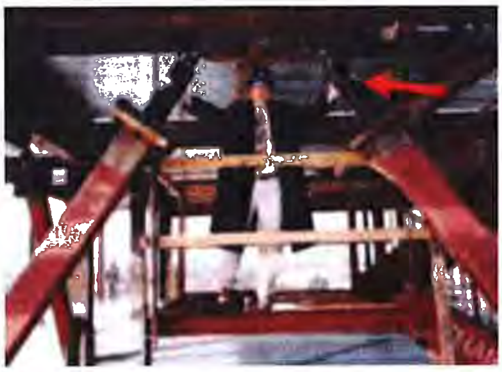
(a) Schematic



(b) Photograph

Figure 5.5. Typical fluid viscous damper.

(http://articles.architectjaved.com/earthquake_resistant_structures/energy-dissipation-devices-for-earthquake-resistant-building-design/



Fluid viscous dampers

Figure 5.6. Application of fluid viscous damper.

http://www.wbdg.org/resources/seismic_design.php)

If the liquid is viscous, these dampers are called viscous dampers or fluid viscous dampers (Figures 5.5 and 5.6) in which energy is absorbed by a viscous fluid compressed by a piston in a cylinder. A fluid viscous damper resembles the common shock absorber such as those found in automobiles. The piston transmits energy entering the system to the fluid in the damper, causing it to move within the damper. The movement of the fluid within the damper fluid absorbs this kinetic energy by converting it into heat. In automobiles, this means that a shock received at the wheel is damped before it reaches the passengers compartment. Buildings protected by dampers as in Figure 5.3 will undergo considerably less horizontal movement and damage during an earthquake. Because the peak dissipater force occurs at the peak velocity, which is out of phase with the peak structural force/displacement, well designed dampers do not increases the forces on the structure. They may also be one of the only ways of minimising the effects of very large near-field pulse type accelerations. However, the cost of viscous dampers is generally considerable.

A variant of the viscous damper is the lead extrusion damper which uses solid lead as the viscous material. (Skinner et al 2000). Much has been written about lead extrusion dampers and how they allow structures to sustain large displacements without any damage. A high-force-to-volume (HF2V) lead extrusion damper has been developed at the University of Canterbury (Rodgers et al. (2010)) shown in Figure 5.7(a). It resists force as a bulge on the shaft pushes through lead as shown in Figure 5.7(b). The lead re-crystallises after the deformation thereby decreasing the likely permanent displacement.


(a) Size of the HF2V device. **(b) Shaft with bulge that passes through lead.**

Figure 5.7. Lead extrusion damping device (Rodgers et al 2010).

5.3.2 Friction dampers

Friction dampers use metal or other surfaces in friction; and energy is absorbed by surfaces with friction between them rubbing against each other. Typically a friction damper device consists of several steel plates sliding against each other in opposite directions. The steel plates are separated by shims of friction pad material as shown in Figure 5.8. The damper dissipates energy by means of friction between the sliding surfaces. Friction dampers can be used in many applications including moment-frames and in diagonal braces, with several of these described in Chapter 7. This type of damper is also being developed for steel sliding hinge frames, as described in Chapter 7.

Figure 5.8. Possible arrangements of steel plates in friction dampers.

5.3.3 Visco-elastic dampers

Another type of damper is visco-elastic dampers which stretch an elastomer in combination with metal parts. In visco-elastic dampers, the energy is absorbed by utilising controlled shearing of solids. The latest friction-visco-elastic damper combines the advantages of pure frictional and visco-elastic mechanisms of energy dissipation. This new product consists of friction pads and visco-elastic polymer pads separated by steel plates. A pre-stressed bolt in combination with disk springs and hardened washers is used for maintaining the required clamping force on the interfaces as in original friction damping concept.

5.3.4 Hysteretic dampers

Hysteretic dampers (also called yielding dampers) are another type of dampers commonly used to dissipate energy in frame buildings. They typically are made of metal parts; in which energy is absorbed by yielding deformation of critical metallic components, usually made of steel. Hysteretic dampers can be designed to yield in bending, or in tension and compression.

Examples of bending devices include U-shaped flexural plates and triangular bending plates, both designed so that the yielding of the steel is spread over a significant length to avoid high strains and low-cycle fatigue. U-shaped flexural plates are used between closely spaced structural walls, as described later. Tension and compression devices are designed for axial yielding, so a high level of lateral restraint is necessary to prevent buckling in compression. The lateral restraint may be provided by steel tubes filled with concrete or epoxy, for example.

5.3.5 Buckling restrained braces (BRB)

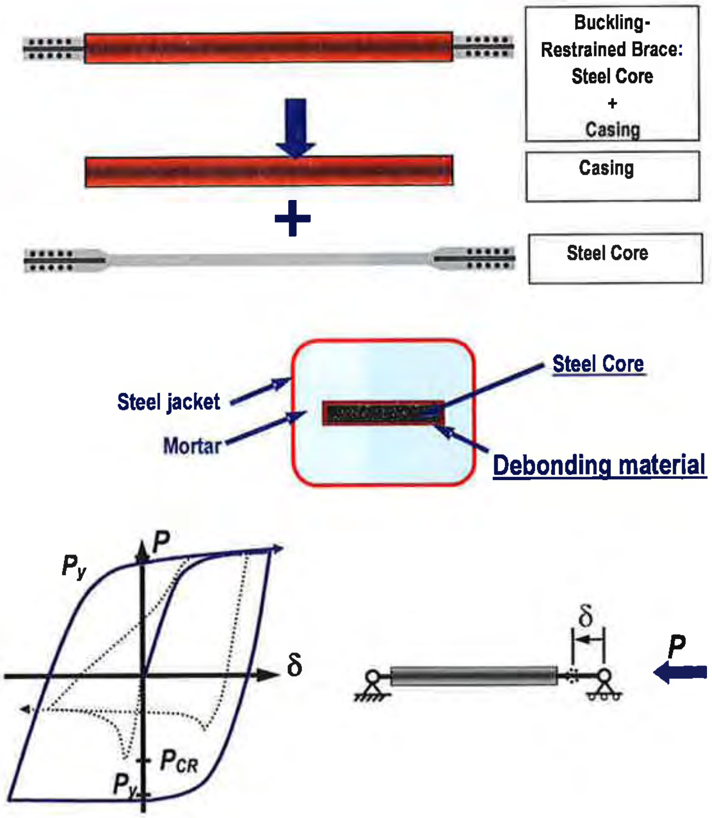


Figure 5.9. Buckling restrained brace and typical hysteresis loop.

Buckling restrained braces (BRB) are a special form of hysteretic damper, with energy dissipation built into a tension-compression brace, in such a way that the damper can yield in both axial tension and compression under reversed cyclic loading. The buckling restraint is needed to prevent the yielding steel component from buckling when loaded in compression. While the BRB sustains damage, the displacements are spread over a long length so that the strains are kept small enough to prevent low cycle fatigue failure.

5.4 Examples of Base Isolation

Some examples of real applications of base isolation and dampers follow.

Figure 5.10. Christchurch Women's Hospital, showing one of 40 lead-rubber bearings.

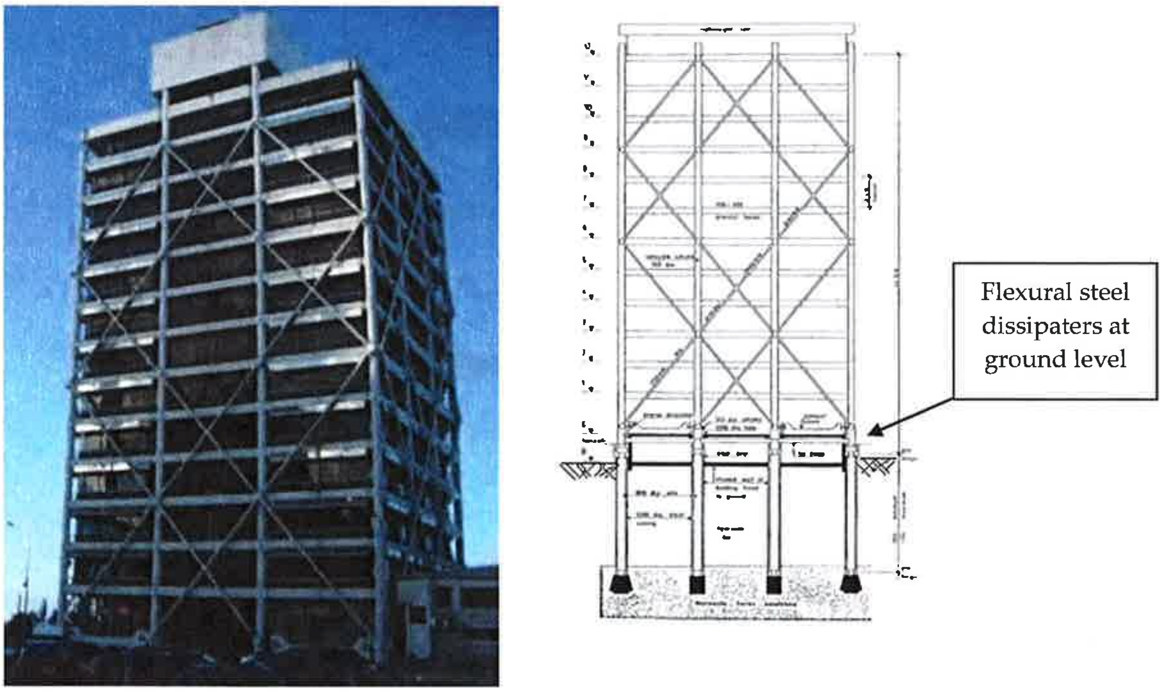
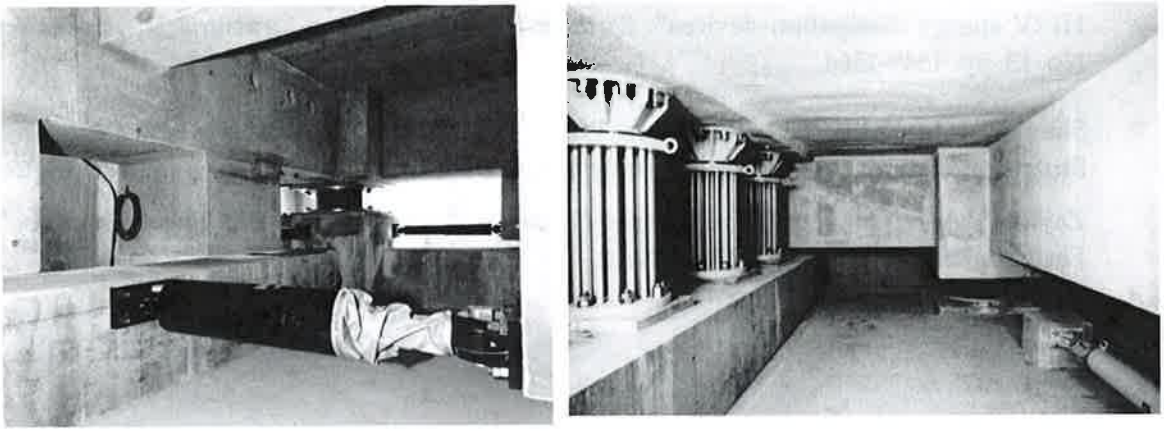


Figure 5.11. Union House, Auckland, base isolated using flexible piles and energy dissipaters.



Viscous dampers and laminated rubber bearings in Test Building at Tohoku University, Sendai, Japan.

High damping rubber bearing, steel dampers and oil damper in basement of Bridgestone Toranomon Building, Tokyo.

Figure 5.12. Base isolators in Japanese buildings (Skinner et al., 2000).

Figure 5.13. Te Papa Museum in Wellington has base isolation with lead rubber bearing (Skinner et al., 2000).

Many examples of steel buildings with damping devices are shown in chapter 8.

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